Smartphone-based multiparameter analysis for remote patient monitoring

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Remote patient monitoring systems are becoming more popular with the emergence of wireless technologies and mobile devices. Smartphone-based analysis proves to be efficient in scenarios when patient is in need of immediate medical care. In this paper we have tested Android smartphone for the acquisition and analysis of multiple biomedical signals, including electrocardiogram, respiration and blood pressure signals. We have incorporated accelerometer data from the smartphone's built-in sensor for the detection of patient's posture and possible falls as well. Our results show that total processing of biomedical signals should not be placed on the smartphone due to the rapid battery depletion. By using early warning score system, smartphone can generate alarms for medical personnel, without significant resource consumption. We have shown that up-to-date smartphones can meet requirements for efficient remote patient monitoring analysis.

1 Introduction

Remote patient monitoring (RPM) systems are rapidly evolving. With the increasing number of elderly and chronically ill patients, it is necessary to provide efficient home-based healthcare services by exploring the usage of modern information and communication technologies. The integration of wireless communications and mobile devices with healthcare service delivery allows for transition of patients from passive recipients to active participants in the process of decision-making and health management. The total number of patients using remote monitoring devices is expected to increase dramatically in the future, with tendencies of RPM becoming standard healthcare service. Mobile devices, especially smartphones have become an integrated part of everyday life, used not only for communication purposes, but in medicine and healthcare as well [1]. As health-related data and applications are being forwarded to the cloud computing systems by smartphones, it is certain that their role will become even more significant for analysis of biomedical signals and patient-related data. Mobile devices in RPM systems were originally used only for the transmission of data to the remote location and visualisation, while server-side component was responsible for providing feedback to the patient. Possible errors in transmission or loss of wireless signal, as well as the rapid improvement of smartphones's features, opened up opportunities for the smartphone-based local analysis that can be executed in real-time. Therefore, it is preferable to provide fast, accurate solutions based on the smartphones to generate early warning in case of emergency. However, smartphones are above all intended for communication purposes and their utilization in RPM systems should be adjusted for specific situations, such as lack of medical care, loss of cellular network signal etc.

In this paper, we have tested Android smartphone for the acquisition and analysis of multiple biomedical signals, including electrocardiogram (ECG), blood pressure (BP) and respiration (RESP) signals. Two scenarios have been implemented; first scenario involves all signal processing operations on smartphone, with constant transmission of the data from the sensor node. Algorithms for the detection of important parameters from biomedical signals, such as heart rate and blood pressure value, have been implemented. Second scenario assumes that wireless sensor nodes execute processing operations for different biomedical signals, and send only required health parameters. In order to generate alarm when detecting abnormal values of mentioned parameters, modified early warning scoring (EWS) system [2] was utilized in both scenarios. In addition, tested biomedical signals have been integrated with accelerometer data acquired from smartphone's built-in sensor, for providing information of patient's posture and possible fall. Our results show that although smartphones are capable of performing signal processing operations in real-time, they are not suitable for long remote patient monitoring due to the rapid battery depletion. This paper offers a better understanding of the smartphone's utilization in RPM system where it is important to define which processing operations are suitable for smartphone application when designing efficient RPM system.

2 The usage of smartphones in remote patient monitoring

The development of remote patient monitoring started with the emergence of wireless sensor nodes (WSN), wireless communications and mobile devices. The basic monitoring operation consists of acquisition of patient's vital signs using WSN equipment and wireless transmission of data using mobile device to a server or network cloud (Figure 1).

Figure 1: General concept of remote patient monitoring system

Using WSN for the acquisition of biomedical signals such as ECG, BP, blood saturation (SpO_2), respiration rate (RESP), electromyogram (EMG) etc and mobile devices in RPM system, helps patients by providing their doctors with continuous access to acquired data and identifying conditions that can easily go undiagnosed if patient is not in medical facility. It is also important to know the location of the patient as well as his posture, due to the possible falls of elderly, which can be achieved by using accelerometer and GPS sensor data.

In order to improve healthcare services, it is important to make acquisition of different vital signs easy and affordable at anytime and anyplace. Wireless sensors nodes have been developed for the unobtrusive acquisition of different vital signs [3][4]. Wireless connection is necessary in order to establish transmission of acquired data to the remote monitoring centre or a hand-held device. With recent developments of features such as HD camera and accelerometer, smartphones can also be used as an acquisition tool. Smartphone application provides a valid measurement of the heart rate [5] and temperature [6], while respiration rate and blood pressure can be estimated by using the heart rate data [7][8]. Main advantage of RPM system is that the usage of smartphone for the acquisition of biomedical signals requires no additional equipment like sensors, cables, electrodes etc. However, acquiring biomedical signals with a smartphone device is intended for short periods of time, which is why they are unreliable in continuous remote patient monitoring.

The smartphones and mobile devices have been tested for different types of applications in RPM systems, such as streaming of biomedical signals [9], display of the data or basic signal processing [10]-[12], and for more complex algorithms[13]. Above listed examples from literature have been tested for analysis of single biomedical signal, usually ECG. Multiparameter analysis, on the other hand, can provide broader insight into the health state of the patient and detect or diagnose conditions that are not visible from single parameter. It is important to acknowledge the significance of context information (age, sex, weight etc) for the analysis, since certain values of parameters can be considered dangerous for one patient and normal for another.

3 Smartphone implementation

In this paper we have tested smartphone for acquisition and analysis of multiple vital signs (Figure 2). Three different biomedical signals (ECG, BP, RESP) have been analyzed on the smartphone. The accelerometer data are gathered from built-in 3-axis accelerometer sensor, which eliminates the need for additional sensor device to be worn by the patient. Accelerometer data provides information of patient's posture and motion, which can be used for the detection of falls or for raising alarm when the patient is too long in a static posture.

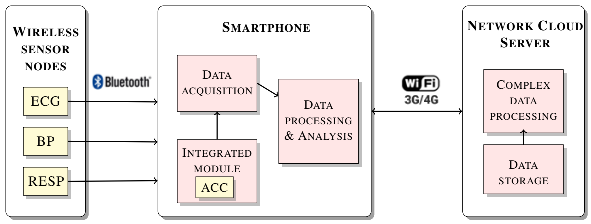

Figure 2: Block diagram of remote monitoring system

Data analysis includes two different scenarios as can be seen in Figure 3. First scenario involves all signal processing operations on smartphone, with constant transmission of the data from the sensor node. While large number of ECG signal processing algorithms were proposed in literature, their implementation on battery powered devices has high demands in terms of numerical efficiency, speed and accuracy [15]. The Pan-Tompkins algorithm [16] for QRS detection and HR calculation was chosen due to its simplicity and efficiency. Blood pressure was calculated from blood pressure signal by using algorithm suggested by Zong[17]. Above listed algorithms were implemented in separate threads on the smartphone, due to the resource-intensive signal processing operations such as noise removal, filtering, integration/differentiation etc.

In the second scenario, we have sent only significant parameters of biomedical data, such as the heart rate, blood pressure and respiration rate. This scenario implies that processing of data is performed on sensor nodes, and not on the smartphone. This assumption can be made due to the fact that WSN are constantly evolving with increased computational performance and smaller size [18]. Based on acquired values, we have implemented Early Warning Score system for generating alarms to a family member or a doctor. The Early Warning Score (EWS) [2] is a simple scoring system that is used by medical staff to quickly identify the patients at risk of deterioration in intensive care. This tool uses five physiological parameters: systolic blood pressure, pulse rate, respiratory rate, temperature and AVPU score, which is a measurement of patient's alertness. Depending on the parameter values, EWS is calculated and compared to the critical values, which are defined by professionals. This approach was

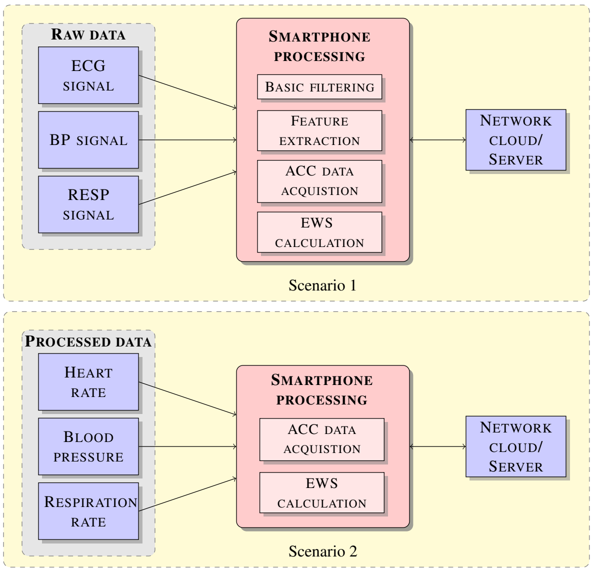

Figure 3: Block diagram of processing operations for different devices in two scenarios

introduced in RPM systems [19], but it required medical staff to manually enter the data for further analysis.

Compared to EWS system suggested in [2], we have used only three parameters (HR, BP, RESP), while replacing data related to the alertness of the patient with accelerometer data gathered by smartphone. By calculating scores based on vital signs parameter values from Table 1, smartphone can initiate alarm by placing a call or sending a text message to medical personnel when patient is in emergency situation.

Table 1: Accelerometer data integration with modified early warning score system [2]

Score	0	1	2	3
Heart rate (bpm)	51 – 100	41 – 50 101 – 110	< 40 111 – 129	≥ 130
Blood pressure (mmHg)	101 – 199	81 – 100	71 – 80 ≥ 200	< 70
Respiration rate (bpm)	9 – 14	15 – 20	< 9 21 – 29	≥ 30
Accelerometer data	Normal movement	Rapid movement	Inaction for longer period / Fall detection	

3.1 Accelerometer data

Accelerometer data was obtained using built-in smartphone's 3-axial accelerometer sensor. It measures the acceleration of smartphone device in all three spatial dimensions (A_x, A_y, A_z). We have placed smartphone on the users's waist, in order to record accelerometer data when user is executing different activities such as standing, sitting, walking, running etc. Figure 4 shows samples of raw tri-axial accelerometer data for different body movements.

In order to detect which physical activity the patient is currently executing, continuous acquisition of accelerometer data is performed. We have tested simple threshold based algorithm [20] for the recognition of patient's movements and for the possible fall detection. The acquired signal magnitude vector A_n is calculated by using raw accelerometer values and compared to the predefined threshold values (Equation 1).

$$A_n = \sqrt{|A_x|^2 + |A_y|^2 + |A_z|^2} \qquad (1)$$

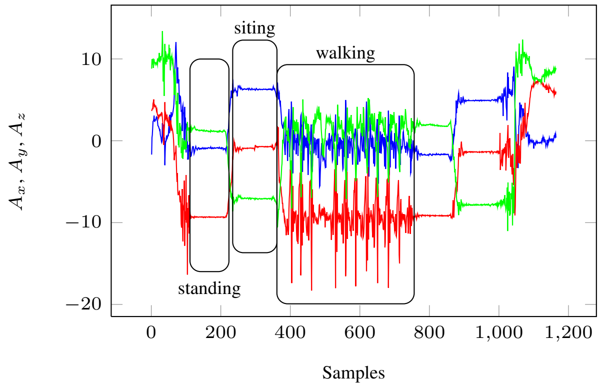

Figure 4: Accelerometer data gathered by smartphone

4 Results

Android based smartphone was chosen because of its open-source platform, lower cost and easily accessed applications. Samsung I9300 Galaxy S III was used for testing. Figure 5 shows screenshot captured in tested Android device, displaying early warning score value, which is calculated based on different parameter values. Chosen datasets[14] provide synhronized multiparameter data from single patient.

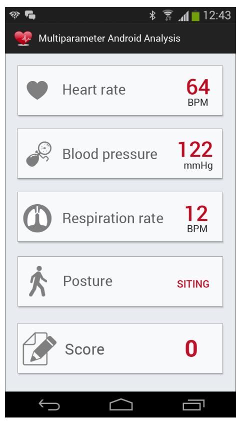

Figure 5: Samsung SIII screenshot of developed Android application

Figure 6 demonstrates computation time needed for processing biomedical signals of different length (1-3 min) for two tested scenarios. Scenario 1 takes raw ECG, BP and RESP data and performs signal processing operations by using previously mentioned algorithms. This scenario has higher computation time due to the fact that smartphones needs to process large amounts of data, e.g. 3

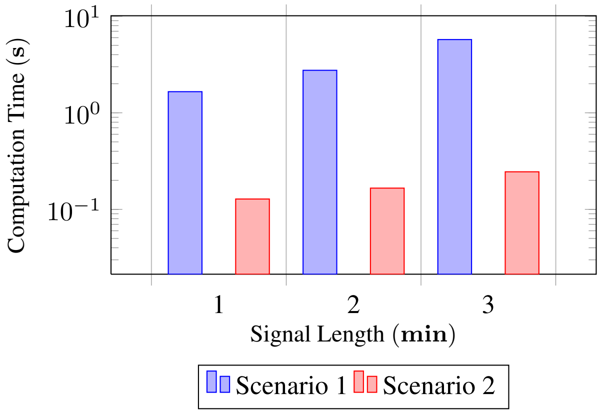

Figure 6: Computation time for tested scenarios

minute acquisition time equals 45 000 samples with 250 Hz sampling frequency. On the other hand, second scenario assumes that wireless sensor nodes execute processing operations for different biomedical signals, and send only important health parameters which require smaller number of samples. Calculations of EWS system, along with simultaneous acquisition of accelerometer data in second scenario do not place restrictions on the basic functioning of smartphone devices.

5 Conclusion

The usage of smartphones and other mobile devices in remote patient monitoring is expected to increase dramatically in the future. In this paper, we have implemented acquisition and analysis of three biomedical signals and accelerometer data using Android smartphone. Our results show that using smartphones for biomedical signal processing operations such as filtering and feature detection leads to greater consumption of resources. By moving above mentioned operations to sensor nodes and using simple early warning score system, it is demonstrated that this type of analysis lowers computation time battery-driven smartphone device for multiparameter analysis. Our future work will focus on investigating the role of smartphones in critical situations, while integrating sensor data with activity sensors data such as number of steps, motion, location etc.

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